

Temperature Dependence of Attenuation of Coplanar Waveguide on 4H High Resistivity SiC Through 540 C

G. E. Ponchak, Z. Schwartz, S. A. Alterovitz, A. N. Downey, J. C. Freeman

For the first time, the temperature and frequency dependence of the attenuation of a Coplanar Waveguide (CPW) on 4H, High Resistivity SiC substrate is reported. The low frequency attenuation increases by 2 dB/cm at 500 C and the high frequency attenuation increases by 3.3 dB/cm at 500 C compared to room temperature.

Introduction: NASA requires sensors with wireless communication capabilities that operate at high temperature (> 500 C) for aircraft engine development and monitoring during flight. Because of the high temperature, wideband gap semiconductors such as SiC are required. SiC resistivity has been characterized as a function of temperature using a four-point probe [1], but this only yields the DC material characteristics of the SiC. To fabricate a wireless communication circuit, the RF characteristics of microwave transmission lines as a function of frequency and temperature are required. In this letter, for the first time the attenuation of a Coplanar Waveguide (CPW) fabricated on a 4H HPSI wafer from Cree is reported over a frequency band of 1 to 50 GHz and a temperature range of 29 C (Room Temperature) to 540 C.

Circuit Description: The substrate is a 4H HPSI SiC wafer from Cree (wafer number BV0302-11, part number W4TRD8R-0D00) with a thickness of 409 μm , a room temperature resistivity greater than 105 $\Omega\text{ cm}$. An RCA clean was performed on the wafer prior to processing. A set of CPW lines with a center conductor width, slot width, and ground plane width of 50, 25, and 150 μm respectively were fabricated on the wafer

using liftoff processing. No insulator was grown over the SiC prior to metal deposition, which consisted of 20 nm of Ti and 1.5 μm of evaporated Au. A set of CPW lines consisted of lines with lengths of 5000, 5850, 6700, 8500, and 17500 μm long.

Measurement Procedure: 1 to 50 GHz measurements are made with an HP8510C Vector Network Analyzer, an RF probe station, and GGB Industries Picoprobes specially built for high temperature probing. Thermal shields were built onto the probes and coaxial cables to reduce the heating of these parts. The conventional probe station wafer chuck was replaced with a specially built wafer chuck consisting of a NASA shuttle tile. Upon the shuttle tile, a computer controlled ceramic heater was placed. The SiC sample was placed on a Si wafer that rested on the ceramic heater. A thermocouple measured the temperature of the SiC wafer during measurements. At room temperature, a full TRL calibration was performed using all of the CPW lines described above and NIST MULTICAL software [2]. Temperature dependent measurements are made every 30 C of the 17500 μm long CPW line.

Results: During measurements, especially above 470 C, the SiC wafer and heater stage glowed red, but the Ti/Au CPW lines showed no visible signs of degradation. However, because the wafer probes were placed down on the CPW probe pads 21 times at high temperature, the probe pads did have visually noticeable wear and resulted in minor scatter of the measurements.

The room temperature attenuation of the CPW line had the typical frequency dependence that includes a constant term to account for the DC metal resistivity and the $\tan \delta = 1/\rho\omega\epsilon'$ portion of the dielectric loss caused by the non-infinite resistivity (ρ) of the SiC substrate,

a linear dependence with frequency term to account for the $\tan \delta = \epsilon''/\epsilon'$, and an $f^{0.5}$ term to account for conductor loss; The measured attenuation is described by:

$$\alpha(RT) = 0.202 + 6.973 \cdot 10^{-3} f + 0.2233 \sqrt{f} \quad (1)$$

where f is in GHz and α (RT) is in dB/cm. At 50 GHz, the room temperature attenuation is 2.2 dB/cm at 50 GHz. The increase in attenuation above the room temperature attenuation as a function of temperature for 1, 25, and 50 GHz is shown in Fig. 1. It is seen that the attenuation increases by 2 dB/cm at 1 GHz when the temperature is raised to 500 C, but the high frequency increase in attenuation is not as dramatic, increasing by only 3.25 dB/cm at 500 C for a frequency of 50 GHz. The increase in attenuation for 25 and 50 GHz is approximately the same.

The attenuation of the CPW line was fit to Equ. 1 at every temperature to determine the nature of the attenuation increase. It is found that the linear term of $\alpha(T-RT)$ is zero, indicating no increase in ϵ'' with temperature. The constant and the $f^{0.5}$ term dependence on temperature are shown in Fig. 2. The constant term is seen to increase significantly as a function of temperature with a T^2 dependence, while the $f^{0.5}$ term increase nearly linearly with frequency.

These results indicate that SiC wireless circuits may be made on SiC wafers for operation at high temperatures, but the attenuation of microwave transmission lines will increase by approximately 3.5 dB/cm at 500 C and 50 GHz. At 1 GHz, the attenuation of the line will increase by 1.75 dB/cm at 500 C. The major reason for an increase in transmission line attenuation as temperature is increased appears to be due to a decrease in the SiC resistivity.

References

1. Clarke, R. C., Brandt, C. D., Sriram, S., Siergiej, R. R., Morse, A. W., Agarwal, A. K., Chen, L. S., Balakrishna, V., and Burk, A. A., "Recent advances in high temperature, high frequency SiC devices," Proc. 1998 High-Temperature Electronic Mater, Devices, and Sensors Conf., Feb. 22-27, 1998, San Diego, CA, pp. 18-28.
2. R. B. Marks, "A multiline method of network analyzer calibration," IEEE Trans. Microwave Theory and Techniques, Vol. 39, pp. 1205-1215, July 1991.

Authors' affiliations:

G. E. Ponchak, S. A. Alterovitz, A. N. Downey, J. C. Freeman (NASA Glenn Research Center, 21000 Brookpark Rd., MS 54/5, Cleveland, OH 44135), Z. Schwartz (Analex Corp. at NASA Glenn Research Center, 21000 Brookpark Rd., MS 54/5, Cleveland, OH 44135)

Email: george.ponchak@ieee.org

Figure captions:

Fig. 1: Measured increase in attenuation of CPW line at as a function of temperature at 1, 25, and 50 GHz.

Fig. 2: Extracted parameter values for the frequency dependent increase in attenuation of CPW lines as a function of temperature.

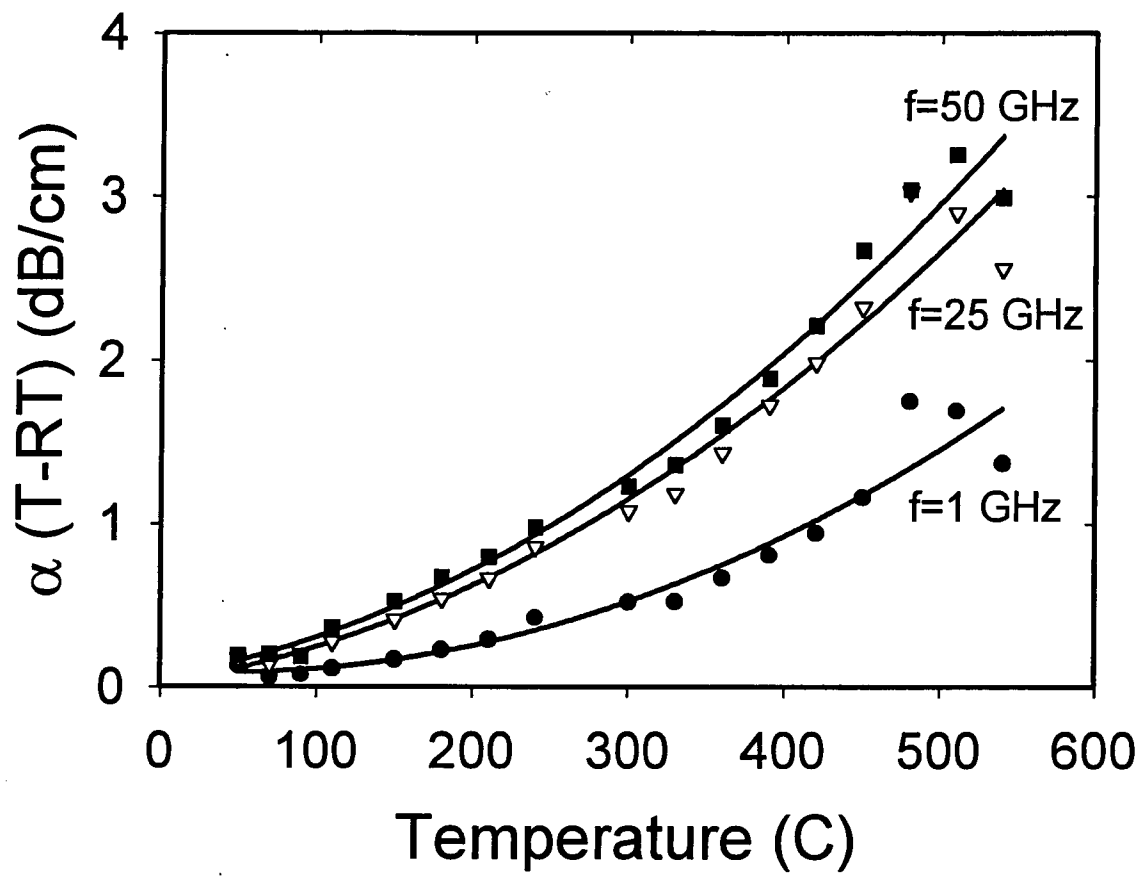


Figure 1

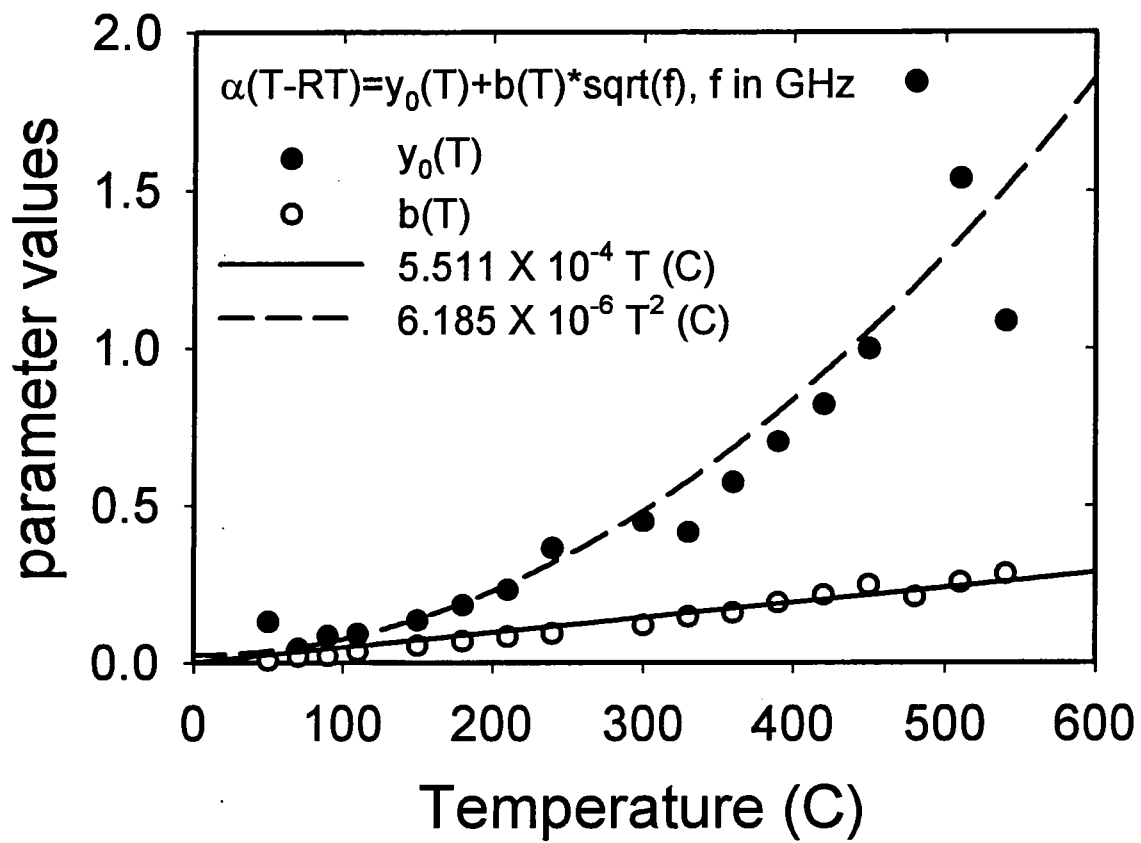


Figure 2